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SPECIAL ISSUE: *Mycotoxins in Africa*

Foreword WMJ special issue 'Mycotoxins in Africa'

This special issue is on mycotoxins in Africa. While the effects associated with mycotoxins have worldwide impact, the population of Africa has suffered the most from them. The climate and agriculture-food production systems prevalent in countries of Africa are favourable for mycotoxin production and accumulation in foods, consequently making populations of many regions of Africa particularly vulnerable to the health and economic impacts of several mycotoxins. The mycotoxins of health concern and economic importance are aflatoxins, fumonisins, trichothecenes, zearalenone and ochratoxin A. The huge burden of mycotoxins is exemplified by the reoccurring outbreaks of mycotoxin poisoning in humans and animals in Africa and the economic consequences of the export barrier to agri-food products. The aflatoxicosis outbreaks in Kenya in 2004 and 2008 as well as in Tanzania during 2016 have claimed hundreds of human lives.

Since the identification of aflatoxins as the cause of Turkey 'X' disease in the 1960's, understanding the properties and significance of mycotoxins has made great advances across many interconnected fields of research. Modern toxicology and epidemiology research have provided substantial insights into toxicities and adverse health effects caused by mycotoxins, such as cancer, impaired child growth and development, immune modulation and endocrine disrupting effects. Recent rapid progress in analytical technology has led to advances in the accuracy, sensitivity and high throughput for mycotoxin detection and quantification in food and feed as well as for biomarkers in human studies. Innovations in agricultural practices have offered potential to prevent or combat mycotoxins. All these factors have contributed to improved knowledge and better understanding of the causes, severity, impact and mitigation possibilities of mycotoxin issues in Africa. More than 90% of young children and mothers in west and east African populations were found to have chronic aflatoxin dietary exposure. This is evidence that high numbers of people in Africa are at risk of aflatoxin-induced chronic diseases. Child malnutrition, which coincides with the high exposure prevalence of aflatoxins and fumonisins, is highly prevalent in many populations in Africa. The epidemiological findings linking mycotoxins and adverse human health outcomes collected in African populations have prompted international and national actions on research (including risk assessment), risk management (including regulation) and mitigation (including risk communication) of mycotoxins. Important and encouraging are the efforts being undertaken by the Partnership for Aflatoxin Control in Africa (PACA) and international collaborative programmes (of which the intercontinental partnership MYTOX-SOUTH is an example).

PACA is a programme of the African Union Commission (AUC) launched in October 2012. It is established as an innovative partnership founded on collaborations among the communities that include organisations and individuals with a stake in aflatoxin control in Africa. PACA is guided by a multi-stakeholder Steering Committee and has a secretariat based at the AUC headquarters in Addis Ababa, Ethiopia. It works with country governments directly while forging strong partnerships with diverse stakeholders to achieve systemic change in aflatoxin control in Africa. After focusing on communication and advocacy to rally the African continent around enhanced aflatoxin control in its early years, PACA has initiated regional and country projects to catalyse aflatoxin mitigation at the grassroots level. PACA is piloting country-led approaches for prioritising, financing and tracking aflatoxin control in six African countries. Results so far indicate that 'placing countries in the driver's seat' could be the game changer for sustainable aflatoxin control in Africa. PACA invites stakeholders to collaborate toward a common vision of 'an Africa free from the harmful effects of aflatoxins'. Read more at http://www.aflatoxinpartnership.org.

MYTOX-SOUTH broadens and consolidates the scientific cooperation between North and South partners on the theme of toxigenic moulds and mycotoxins with the ultimate goal to strengthen the capacity of the developing countries and making research and development more sustainable. MYTOX-SOUTH is structured to bring together researchers with complementary expertise in different areas of mycotoxin research, and includes partners from Europe, the USA, Asia, Latin America and Africa. It is a balanced network of experts striving to improve human and animal health. Currently almost all SOUTH partners are from Africa. MYTOX-SOUTH aims to improve food security and food safety through mitigation of mycotoxins at global level with the following long-term goals: (1) building human capacity through education; (2) bridging the gap between research and development of safe food and feed, and different actors including farmer organisations, NGO's, the private sector and policy makers; and (3) creating a sustainable network to strengthen research capacity. Examples of activities by MYTOX-SOUTH are organisation of dissemination and awareness workshops in the South, organisation of training programmes in the North and South, provision of scholarships for short-term research stays for PhD students and organisation of joint PhD programmes. More information can be found at https://mytoxsouth.org.

In this issue of *World Mycotoxin Journal*, various aspects of mycotoxins in Africa are covered, including mycotoxin determination, occurrence in food and feed, human exposure, health impacts, and strategies for pre-and postharvest prevention and control, including decontamination and detoxification solutions. Geographically, focus is put on various regions of the continent of Africa. Many studies included in this Africa special edition were conducted partially, or solely, by African researchers indicating the commitment to enhancing research capacity on mycotoxin control within Africa by Africans themselves.

An outbreak of an unknown disease (June 2016) in clusters of families from different villages in the central part of Tanzania resulted into severe illness and deaths. With the absence of infectious agents, further investigation was crucial. Kamala *et al.* (2018a) conducted a rapid epidemiological survey in the affected villages. Cases of jaundice, abdominal pain or swelling, diarrhoea or general body weakness were obtained from health facilities two months prior and one month after the outbreak. Blood samples from 24 cases and 23 unmatched controls were analysed for biomarkers of aflatoxin exposure. From the affected households, food samples were collected for mycotoxin analyses. The link between high levels of aflatoxins in the food and high levels of serum aflatoxin-lysine or aflatoxin-albumin adduct clearly indicated that the outbreak was due to aflatoxin poisoning. The responsible food item appeared to be home-grown maize. The authors further reported a co-occurrence of aflatoxins and fumonisins in 69% of the sub-samples. Immediate intervention strategies included the replacement of contaminated maize, extensive public awareness and extension of the survey to neighbouring affected areas. The findings of this study show the need to develop strategies that combat multiple mycotoxins from farm to fork to prevent mycotoxin outbreaks as described in this research paper.

Low-income communities are often the most vulnerable to agricultural products being contaminated with mycotoxins such as aflatoxins, fumonisins, deoxynivalenol, nivalenol and zearalenone. The possible relationship between exposure to these mycotoxins and reproductive health problems in Africa is reviewed by Eze *et al.* (2018). A high prevalence of blood aflatoxin-albumin adducts has been reported in pregnant women and in cord blood, which shows exposure to aflatoxins starts *in utero*. Studies showing associations between aflatoxin exposure and anaemia in pregnancy, low birth weight and male infertility are also reviewed. Reproductive and developmental toxicity of fumonisin B_1 in humans is limited except for the report that links fumonisin B_1 exposure during pregnancy to neural tube defects in offspring. There is a paucity of research regarding the effects of deoxynivalenol and nivalenol on human reproduction and development, although animal studies and *in vitro* models show that deoxynivalenol can impair reproduction and development. Exposure to zearalenone is correlated with high serum oestrogen levels that are linked to precocious puberty and thelarche in girls. Because the molecular pathways through which mycotoxins induce reproductive and developmental toxicity are still not well understood, the authors recommend the use of validated biomarkers of mycotoxin exposure in epidemiological studies to further elucidate the problem.

Countries such as Kenya, that have experienced various aflatoxicosis outbreaks over the last decades, are more aware of the problem and are likely to invest more in its mitigation. Mutegi *et al.* (2018) reviewed the aflatoxin situation in Kenya and evaluated the effectiveness of various mitigation measures adopted to manage the problem. The review shows the impacts that aflatoxins have caused in health and trade as well as measures that have been adopted to control the problem. The review, further, identified measures that have promising results in the combat of aflatoxins and which may be adopted by other countries in Africa where aflatoxin contamination in food is a problem. These range from capacity development in terms of human resources as well as infrastructure; government and private sector initiatives to support cost-effective management efforts and to sustained public awareness for keeping momentum in these efforts; and to stimulate risk assessment to ensure that well-thought-out and enforceable standards for mycotoxins in Africa are in place.

In Ethiopia, wheat and teff (a gluten-free cereal) are among the most important cereal grains, both in terms of production and consumption. While generally there are a lot of data about ochratoxin A in wheat, this information is rather scarce for Ethiopia and hardly exists for Ethiopian teff. Therefore, Geremew *et al.* (2018) developed an analytical method to determine ochratoxin A in wheat and teff. The method was based on alkaline extraction, solid-phase extraction clean-up and HPLC with fluorescence detection.

Its performance characteristics fulfilled the criteria laid down by EU legislation. A survey of 60 flour samples, 30 teff and 30 wheat, destined for human consumption, from 10 suburbs of Addis Ababa showed that ochratoxin A could be detected in 20% of teff and in 50% of wheat samples. Median ochratoxin A levels in teff flour were sevenfold lower than in wheat flour. This makes Ethiopian teff also potentially interesting for the world market.

A substantial part of Africa's agricultural produce is intended for use as animal feed. In a large multi-mycotoxin survey by Gruber-Dorninger *et al.* (2018), more than 1,300 samples of animal feed, collected from various parts of Africa in the period 2014-2017, were investigated. The results provide a unique overview of the occurrence of several major mycotoxins in animal feed, produced in Africa. The data also give insight in the co-occurrence of many other fungal metabolites in finished feed and feed raw materials. The authors concluded that aflatoxins frequently occurred at levels above 20 ng aflatoxins/g, while the major *Fusarium* mycotoxins zearalenone, fumonisins and deoxynivalenol were prevalent in many commodities from all 14 countries, albeit at concentrations mostly below EU guidance values. Zearalenone and deoxynivalenol frequently co-occurred, a finding which may be relevant to feed safety, in view of reported additive and synergistic effects. Several modified forms of major mycotoxins could be detected as well and various other less investigated fungal metabolites frequently occurred or reached high concentrations.

The high temperatures and high relative humidity in the North African countries may favourably influence fungal growth and subsequent contamination of foods and feeds with mycotoxins. Tantaoui-Elaraki *et al.* (2018) reviewed the available literature and revealed that data on food and feed contamination by mycotoxins in Northern Africa are sparsely distributed in space and in time. Nevertheless, the authors were able to find information about toxigenic fungi and mycotoxins in various foods and feeds, including raw cereals, bread, couscous, pasta, milk, spices, wine, beer, fruit juices, olives and olive oil, dried fruits and nuts, and poultry feeds. The researchers showed further that mycotoxin-contaminated food commodities, such as mouldy nuts and dried figs are still freely marketed on the shelves in Algeria, Morocco and Tunisia. While steps have been undertaken towards better prevention of mycotoxin production, it was clearly shown that there is a need for mycotoxin scientists as well as food regulatory bodies from these Maghreb countries and beyond to cooperate to ensure better protection of consumers against mycotoxins.

Mycotoxin contamination in spices is a threat to human health and trade, because of the substandard hygienic conditions prevailing in the developing countries where the spices are produced or marketed. Motloung *et al.* (2018) evaluated the situation of multiple mycotoxin contamination of spices in South Africa, using a validated LC-MS/MS method after sample extraction and clean-up with QuEChERS. Results revealed that almost half of the investigated samples were contaminated with multiple mycotoxins including sterigmatocystin, 3-acetyldeoxynivalenol, fumonisin B_1, fumonisin B_2 and roquefortine, in addition to aflatoxins and ochratoxin A, which are known as common mycotoxins in spices. The results of the investigations emphasise the importance of good agricultural practices, good manufacturing practices and HACCP along the value chain of these South African spices. This study provides a comprehensive assessment of mycotoxin contamination of spices and is expected to trigger more surveillance and control of mycotoxins for those commodities.

Contamination of groundnuts and maize by aflatoxin B_1 increases the risk of chronic aflatoxin exposure in vulnerable African populations. Xu *et al.* (2018) reviewed results from six recent studies from the University of Leeds that used an ELISA to analyse blood samples for the aflatoxin-albumin biomarker of exposure. The review shows widespread aflatoxin exposure in African populations with geometric mean levels of the aflatoxin-albumin adduct ranging from 9.7 pg/mg albumin in Ugandan children to 578 pg/mg albumin in Kenyan adolescents during an acute aflatoxicosis outbreak. Factors contributing to the variation in aflatoxin exposure studies such as diet and age, geographical and seasonal variation, are discussed. Consumption of stored crops, peanut consumption, and higher local humidity tended to be linked to higher exposure. Aflatoxin-albumin levels in serum were lower in breastfed children compared to weaned children, in whom levels quickly reflected those seen in adults. This review highlights once again the urgent need for intervention strategies in sub-Saharan Africa, that are easy, feasible and acceptable to reduce aflatoxin exposure from *in utero* right through to adulthood.

Fumonisin B_1 contamination is significantly higher compared to other mycotoxins in Zimbabwean subsistence grown maize. Ndemera *et al.* (2018) studied the effect of agronomic practices on fumonisin B_1 contamination in an investigative field survey in Manicaland and Mashonaland West, to allow the identification and optimisation of future management practices. Maize grain from selected subsistence farming households were collected during harvest, three and six months post-harvest. A validated LC-MS/MS method for the detection and quantification of 23 mycotoxins was used to quantify mycotoxins in the maize samples. Agronomical practices such as land preparation, pre-harvest, harvest and post-harvest as well as meteorological data were collected. In this study, the authors confirmed that fumonisins were prevalent in samples at harvest (23%), three (47%) and six (47%) months post-harvest. Factors that had a significant influence on fumonisins include seed choice, fertiliser application, maximum temperature at flowering stage and rainfall. The authors concluded that there is a need to further investigate the post-harvest practices, prevailing storage conditions and climatic characteristics during storage in relation to mycotoxin contamination in maize, to model this contamination and obtain a true picture from point of cultivation to point of processing and/or consumption.

Despite the introduction of Aflasafe™ as a biological control product for aflatoxins in some countries of Africa, there is limited information regarding its acceptance, adoption and sustainability. Thus, a study was conducted in Nigeria by Johnson *et al.* (2018) to examine the levels of aflatoxin and Aflasafe™ awareness and understanding among smallholder maize farmers. In addition, the factors affecting Aflasafe™ purchase patterns and sustained usage over multiple growing seasons by farmers were evaluated. Results from the study suggest that the level of awareness of aflatoxin was very high in states where Aflasafe™ was promoted as an intervention for aflatoxin management. Furthermore, it was found that farmers, who use Aflasafe™ combined with other inputs, were more likely to persist in using the product. Therefore, continued interventions, promotion and general education of the public are recommended for increased awareness, trials and adoption of Aflasafe™ in Nigeria and any other countries where Aflasafe™ is already introduced.

Mycotoxin contamination can be significantly elevated post-harvest and during storage. Good post-harvest handling and storage practices, particularly those meeting local practices and culture, are important for reducing mycotoxins. An intervention package of this kind involving hand sorting, sun-drying maize on mats, use of an insecticide and de-hulling of maize was developed by Kamala *et al.* (2018b). Its effectiveness of aflatoxin/fumonisin reduction was tested in a cluster randomised controlled study in three areas of Tanzania. The intervention reduced aflatoxin and fumonisin levels in maize during storage by 83 and 70%, respectively. Consequently, the exposure estimates and risks for aflatoxin and fumonisin in young children were also reduced. The intervention is applicable in communities where humid climate conditions favour aflatoxin and fumonisin production. Limitation of the study design, however, prevented from drawing a conclusion whether or not the intervention has any impact on child growth improvement.

Another potential solution for aflatoxin and fumonisin reduction in maize grain was the use of hermetic storage bags to replace conventional bags. Airtight storage creates a modified micro-atmosphere with deficient oxygen and enriched carbon dioxide that limits fungal growth and mycotoxin production. The effectiveness of hermetic storage on aflatoxin and fumonisin reduction was examined and reported by Murashiki *et al.* (2018). Aflatoxin B_1 had detectability rates below 10% in samples upon harvest. The aflatoxin B_1 detectability rate and level of contamination remained low after being stored in hermetic devices, but they were significantly elevated after conventional storage. Fumonisin B_1, on the other hand, was found to be highly prevalent and detectable in all maize samples upon harvest. Fumonisin B_1 levels did not differ significantly between the hermetic and conventional storage. The authors concluded that the hermetic device was not effective in limiting fumonisin B_1, but was effective in limiting aflatoxin B_1 production during storage. They recommended that hermetic technologies can be adopted by small subsistence farmers for reducing aflatoxin B_1.

Traditional fermented beverages, processed from cereals, are widely consumed in Africa. While cereals grown in Africa are often contaminated with multiple mycotoxins, knowledge about the transfer of these mycotoxins from ingredients to beverages is scarce. Hence Misihairabgwi *et al.* (2018) studied the diversity of fungal metabolites and their fate during processing in *oshikundu*, a popular non-alcoholic fermented beverage frequently consumed in northern regions of Namibia, produced from pearl millet meal and sorghum malt. More than 100 samples of the grain ingredients and *oshikundu* were analysed for 700 fungal, bacterial and plant metabolites, using LC-MS/MS. *Aspergillus* metabolites were most prevalent, including aflatoxins. High levels of cyclopiazonic acid and nitropropionic acid in sorghum malts were found. *Fusarium*, *Penicillium*, *Alternaria* and *Claviceps* mycotoxins were detected as well. It appeared that mycotoxin transfer rates from cereals to *oshikundu* were generally above 50%, which made the authors conclude that good quality ingredients for preparing *oshikundu* and assessment of consumer exposure to mycotoxins in Namibia are necessary.

We sincerely thank the authors and the reviewers of the articles in this issue of *World Mycotoxin Journal* for their contributions. Amare Ayalew and Marthe De Boevre are acknowledged for providing the paragraphs about PACA and MYTOX-SOUTH in this foreword. We hope that the contents of this special issue will provide insight into the various aspects of mycotoxins in Africa, the progress made in research and the prospects and practical applications to mitigate mycotoxin problems. We trust that this special edition will lead to further research and intensified collaboration in the field of mycotoxins in Africa, thus contributing to protecting the population in Africa from harmful effects of mycotoxins.

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